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GEOLOGICAL SURVEY

Selected physical properties of rocks from the Baid al Jimalah West tungsten deposit, Kingdom of Saudi Arabia, and recommendations for geophysical surveys.

by

Mark E. Gettings 1/

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ABSTRACT

Bulk density and magnetic susceptibility of 11 outcrop samples representing the Proterozoic lithologic units at the Baid al Jimalah West tungsten deposit, Kingdom of Saudi Arabia were measured. Induced polarization response, apparent resistivity, and electromagnetic conductivity were determined for four specimens of the sample suite.

Measurements show that there is a negative density contrast of about -0.17 g-cm^{-3} between metasedimentary rocks of the Murdama group and the Baid al Jimalah granite and that this contrast decreases with increasing mineralization of the granite. Similarly, the bulk magnetic susceptibility of the granite is about one-third that of the Murdama rocks for this sample suite; however, magnetic susceptibility increases with increasing mineralization in the granite specimens.

Electromagnetic conductivities are uniformly low, in part because the specimens are weathered, but probably also because intense silicification accompanies the mineralization.

Induced polarization chargeability increases in the granitic specimens with increasing mineralization and reflects higher percentages of sulfide minerals. Chargeability for the mineralized rocks is about four times higher than for the Murdama host rocks, and apparent resistivity values are about one-fifth the values of host rocks.

Based on these results, it is recommended that during reconnaissance exploration of the area 15 detailed high-precision gravity profiles at 10 m to 50 m station spacing and eight induced polarization dipole-dipole profiles at 25 m dipole spacing and maximum "n" of 6 be measured. To help define subsurface structure, a high-precision, ground-magnetic survey (map at 2-gamma contour interval) and a four-channel gamma ray spectrometric survey on a 25x50 m grid covering the area of the profiles are recommended.

INTRODUCTION

The Baid al Jimalah tungsten deposit was discovered in March 1980 by the U.S. Geological Survey during a program of 1:100,000-scale geologic mapping (Cole, in press; Cole and others, 1981). The deposit is recorded in the Mineral Occurrence Documentation System (MODS) under the name Baid al Jimalah West (MODS02661, lat 25°09'25" N., long 42°41'05" E.). A lead-zinc-silver deposit, located 1.5 km to the east (lat 25°09'30" N., long 42°42'10" E.) and previously known simply as Bede el Gemala (MODS00960), was renamed Baid al Jimalah East for clarity and because Cole and others (1981) infer that the two deposits are genetically related. Inquiries regarding the MODS data bank may be made through the Office of the Technical Advisor, Deputy Ministry for Mineral Resources, Jiddah, Kingdom of Saudi Arabia.

This report gives the results of a series of measurements of selected physical properties of rocks from outcrop samples taken at the deposit and from the surrounding area. The purpose of the work was to determine what kinds of geophysical survey methods might best be employed to evaluate the subsurface extent and structural configuration of the deposit. Measurements were made in May, August, and September 1981 on this suite of samples in advance of a joint investigation-evaluation program by the U.S. Geological Survey Mission and the Riofinex Geological Mission of the Baid al Jimalah West deposit.

Results on which this report is based were obtained in accordance with a work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS) under subproject 5.12.07, Geophysical reconnaissance of the Baid al Jimalah tungsten deposit. Laboratory determinations were performed in the USGS rock physical properties laboratory at the USGS Saudi Arabian Mission, Jiddah.

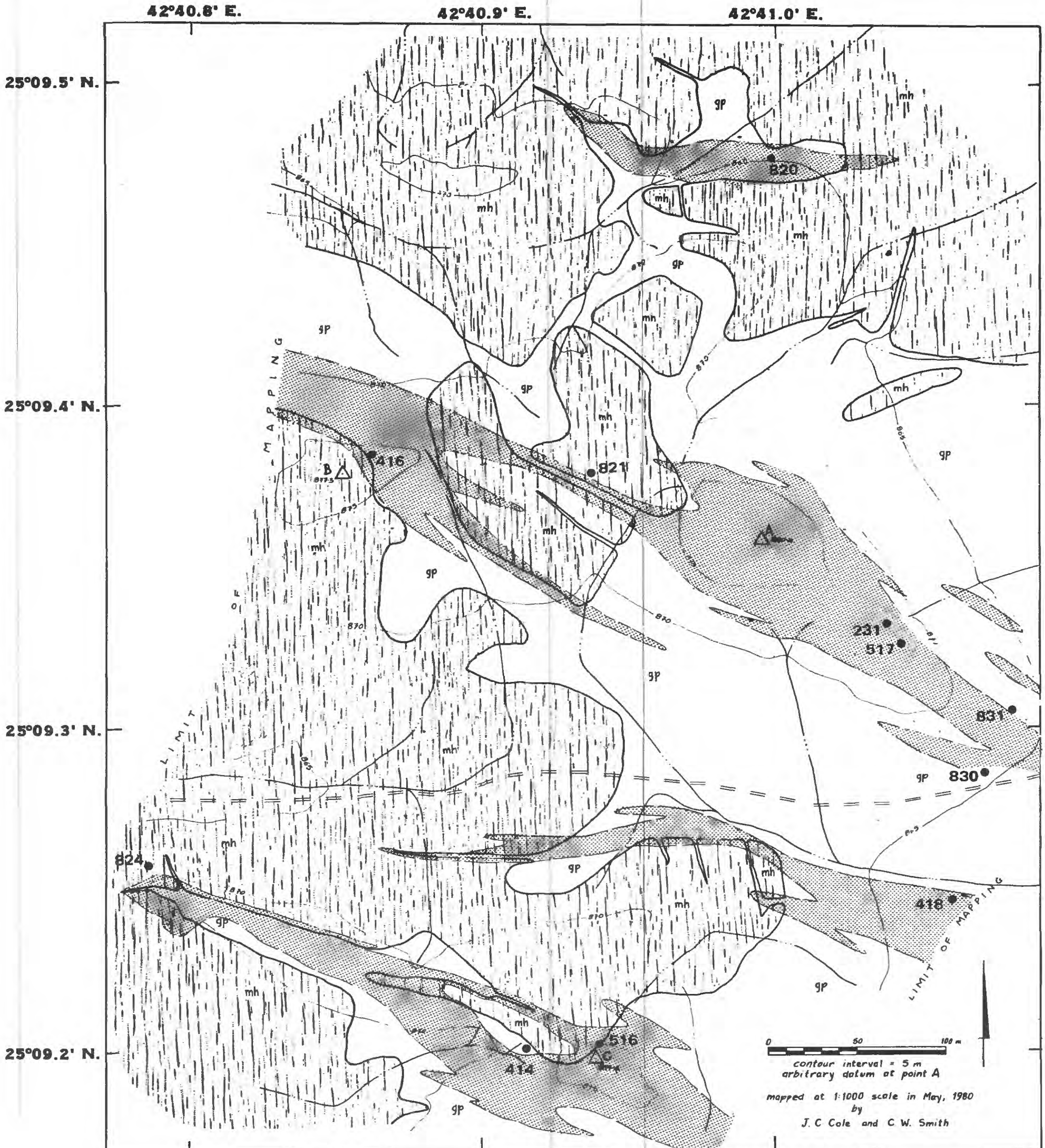
The summary of the geologic setting of the tungsten deposit was compiled from the 1:100,000-scale reconnaissance geologic mapping of Cole (in press) and from the preliminary investigation of the deposit by Cole and others (1981). The surface exposure of the Baid al Jimalah West tungsten deposit is composed of wolframite contained in quartz veins and stockworks that cut a small cupola of microcline-albite granite and the surrounding metasedimentary rocks. The granite is located on the east limb of a south-plunging synform of Murdama group metasiltstones, metasandstones, and metadiabase sills that have been regionally metamorphosed to lower greenschist facies assemblages, and that are further metamorphosed near the granite contact to assemblages containing fresh biotite and porphyroblastic fluorite. The terrain in the vicinity of the deposit is nearly flat; subtle ridges of less than 15 m local relief correspond to areas underlain by closely spaced quartz veins and silicified granite and wall rock.

The deposit is about 11 km east of the axis of the synform in a thick sequence of folded Murdama metasediments immediately below the projected position of a subhorizontal unconformity with the overlying Al Jurdhawiyah group rocks, which in this area are composed of volcanic conglomerates and andesite flows and flow breccias. The Murdama group rocks dip 45° to 60° W. and strike approximately north-south, whereas the Al Jurdhawiyah group rocks dip about 25° NW.

The exposed area of the deposit (fig. 1), which is approximately 700 m in diameter, encloses the irregular outcrop outline of microcline-albite granite, stockworks, and veins. The granite is commonly greisenized to varying degrees (silicification and replacement by muscovite and fluorite) and contains tungsten mineralization associated with late stage hydrothermal quartz vein stockworks. The stockworks cut the granite and extend into the host rocks along a west-northwest direction. Mineralization includes wolframite, scheelite, local cassiterite, and minor sulfides (mainly pyrite, chalcopyrite, and arsenopyrite with minor pyrrhotite and late sphalerite) in the quartz vein stockworks and the selvages of the veins. There is some mineralization in the vein selvages where the stockworks cut the hornfels and granite.

The granite appears to have been a porphyritic biotite-bearing microcline-albite granite before alteration that was subsequently greisenized, fractured, and veined by hydrothermal (late-stage magmatic) fluids. An estimated 15 percent of the outcrop of greisenized granite consists of vein material. Wolframite is the dominant ore mineral in the quartz veins and locally comprises up to a few percent of the veins, although average contents are lower and erratic. The sulfide minerals are commonly present in the vein selvages and consist of varying amount of pyrite, arsenopyrite, chalcopyrite, pyrrhotite, and sphalerite. Patches of disseminated sulfide minerals in the wall rocks are common where they are intruded by the vein stockworks.

A lead-zinc-silver deposit (Baid al Jimalah East; MODS00960) is present about 1.5 km east of the tungsten-bearing granite. In this deposit, slightly brecciated quartz veins contain similar sulfide minerals (including common galena); grab samples contain anomalous tin (Cole and others, 1981). Both at this deposit and Baid al Jimalah West, the veins have essentially the same west-northwesterly trend.



Surficial deposits not shown

EXPLANATION

gp	MICROCLINE-ALBITE GRANITE--Medium-grained, porphyritic; dense dike swarms, contacts enclose areas chiefly of granite		CONTACT--Generalized
			WADI
mh	MURDAMA GROUP--Fine-grained, massive fluorite-biotite hornfels; grades away from granite into metasiltstone and metasandstone		DIRT ROAD
		△A 980.0	TRIANGULATION STATION AND ALTITUDE--In meters
	ZONE OF DENSE QUARTZ-WOLFRAMITE VEINS--Unit gpv, table 1	• 830	SAMPLE LOCATION FOR ROCK FOR PHYSICAL PROPERTIES MEASUREMENT--Prefix 152-

Figure 1.--Geologic sketch map of the Baid al Jimalah West tungsten deposit showing locations of specimens used in physical properties measurements. Base map and geology from Cole and others (1981). Petrographic descriptions are given in table 2.

Comparison of these trends with the regional fault and structural trends shown on the geologic map (Cole, in press) and the trends in the regional aeromagnetic data, (Kleinkopf and Cole, 1982/1983) suggests that the vein systems are related to each other.

RESULTS OF PHYSICAL PROPERTIES MEASUREMENTS

Bulk density and magnetic susceptibility measurements were carried out on 11 specimens of the various rock units of the deposit. Four of these specimens were large enough for cores to be drilled from them, from which induced polarization, apparent resistivity, and electromagnetic conductivity measurements could be made. All specimens were obtained from J. C. Cole, and all measurements were completed by M. N. Jama or M. E. Gettings in the USGS rock physical properties laboratory. Specimen bulk densities were determined by weighing in air and in water on an electronic digital-readout balance. Specimen magnetic susceptibility, electromagnetic conductivity, induced polarization (IP) chargeability, and apparent resistivity were determined using a Scintrex CTU-2 core testing unit with IP module and a Scintrex IPR-8 IP receiver. The results of these measurements are summarized in table 1. Petrographic descriptions are given in table 2, and sample locations are shown on the geologic sketch map (fig. 1).

The scatterplot of the density determinations (fig. 2) shows that the granite ranges in bulk density from about 2.5 to 2.68 g-cm^{-3} depending on the degree of alteration (greisenization) and mineralization. The only unaltered granite sample available, number 152820, has a density of 2.573 g-cm^{-3} (bulk density values reported here are accurate to about 0.005 g-cm^{-3}). The fact that the two specimens of Murdama group host rock have an average density of about 2.77 g-cm^{-3} implies that the density contrast between the granite and the host rocks is about -0.17 g-cm^{-3}.

A scatterplot of the results of magnetic susceptibility measurements (fig. 3) shows that, although the magnetic susceptibilities are uniformly small, that is, about 1E-5 ($1x10^{-5}$) emu-cm^{-3}, the magnetic susceptibility of both the metasiltstone and the metadiabase of the host rocks is about two to four times that of the granite and mineralized granite specimens. The magnetic susceptibilities of the granite and greisenized granite range from 0.8E-5 to 3E-5 emu-cm^{-3}, whereas those of the host rocks are about 4E-5 emu-cm^{-3}. The systematic variation with rock type shown in figures 2 and 3 suggests that detailed gravity and ground magnetic surveys should delineate the structural configuration of the granite that intrudes the host rock.

Table 1.--Results of physical properties measurements of selected samples from the Baid al Jimalah West tungsten deposit [See table 2 for petrographic descriptions and figure 1 for sample locations. "E" notation signifies the exponent of the power of 10, for example, 2.90E-5 = 2.90×10^{-5}]

Sample number	Density $g\text{-}cm^{-3}$	Magnetic susceptibility $emu\text{-}cm^{3}$	Electromagnetic conductivity $mho\text{-}m^{-1}$	Induced polarization chargeability msec	Apparent resistivity ohm-m	Map unit (fig. 1)	Lithology and remarks
152231	3.195	2.90E-5	--	--	--	gpv (veins)	Coarse, bladed, crystalline wolframite
152414	2.628	2.05E-5	--	--	--	gp	Stongly greisenized granite
152416	2.618	1.1E-5	--	--	--	gpv	Moderately greisenized granite
152418	2.589	9.7E-6	--	--	--	gpv	Strongly greisenized, somewhat hematitic granite
152516	2.595	<8E-6	--	--	--	gpv	Veined, greisenized granite
152517	2.678	1.5E-5	--	--	--	gpv	Strongly greisenized granite
152820	2.573	1.1E-5	<0.2	16.9, 15.7, 19.8	214, 202, 379	gpv	Fresh biotite microcline-albite granite
152821	2.798	4.2E-5	--	--	--	mh	Fine-grained recrystallized diabase sill/flow in Murdama
152824	2.754	4.1E-5	<0.2	6.8	508	mh	Murdama metasiltstone
152830	2.521	<8E-6	<0.2	10.1	331	gpv	Moderately greisenized granite
152831	2.525	2.2E-5	<0.2	27.9	121	gp	Strongly veined and greisenized granite

Table 2.--Petrographic descriptions of samples of the Baid al Jimalah West tungsten deposit used in the physical properties measurements [Descriptions provided by J. C. Cole; sample locations shown in figure 1]

Sample number	Description
152231	Coarse, bladed, crystalline wolframite typical of the deposit
152414	Strongly greisenized granite of Baid al Jimalah; consists almost entirely of quartz (60 percent, both large grains and radial fibrous (chalcedonic) varieties), and decussate-plumose muscovite (35 percent) with 2 to 3 percent fluorite, some zircon, and secondary carbonate
152416	Moderately greisenized granite porphyry consisting of quartz (45 percent), muscovite (25 percent), and altered potassium feldspar (20 percent); 5 percent fluorite, fairly common zoned zircon, and a few large grains of zoned and twinned cassiterite; rock cut by numerous thin quartz veins
152418	Strongly greisenized and somewhat hematitic granite consisting of quartz (80 percent), muscovite (20 percent), and trace amounts of zircon, rare fluorite, cassiterite, and possible wolframite
152516	Veined, greisenized granite; veins contain zoned fluorite, scheelite, and small patches of weathered(?) wolframite
152517	Strongly greisenized granite consisting of quartz (65 percent), muscovite (20 percent) + sericite (15 percent), and traces of zircon, cassiterite, and wolframite
152820	Fresh biotite microcline-albite granite porphyry of Baid al Jimalah; appears to be uneffected by greisenization
152821	Fine-grained recrystallized nonporphyritic diabase sill/flow within Murdama group metasiltstone; consists of quartz, plagioclase, and abundant biotite, amphibole, secondary fluorite, and traces of cassiterite
152824	Murdama metasiltstone; quartz, indeterminate feldspar, abundant biotite, and some muscovite; may contain minor disseminated pyrite or pyrrhotite, although probably oxidized in this sample
152830	Moderately greisenized granite porphyry (biotite altered to muscovite, feldspars still intact); minor quartz veins appear unmineralized in this sample; slightly reddish (hematitic?)
152831	Strongly veined and greisenized granite consisting only of quartz, muscovite, and relics of disseminated pyrite(?) and wolframite(?)

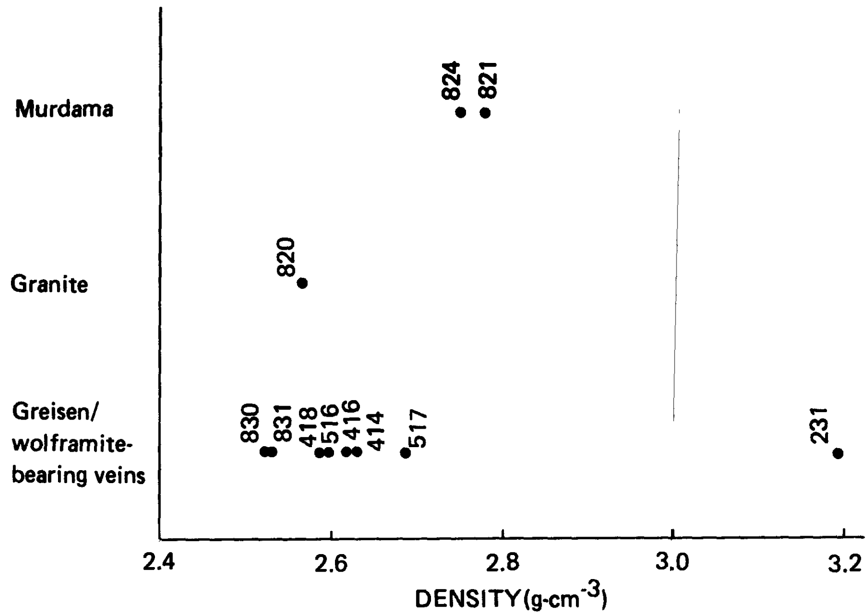


Figure 2.--Scatterplot of bulk density determinations for Baid al Jimalah West specimens. Numbers above points are the last three digits of the sample number, prefix 152-.

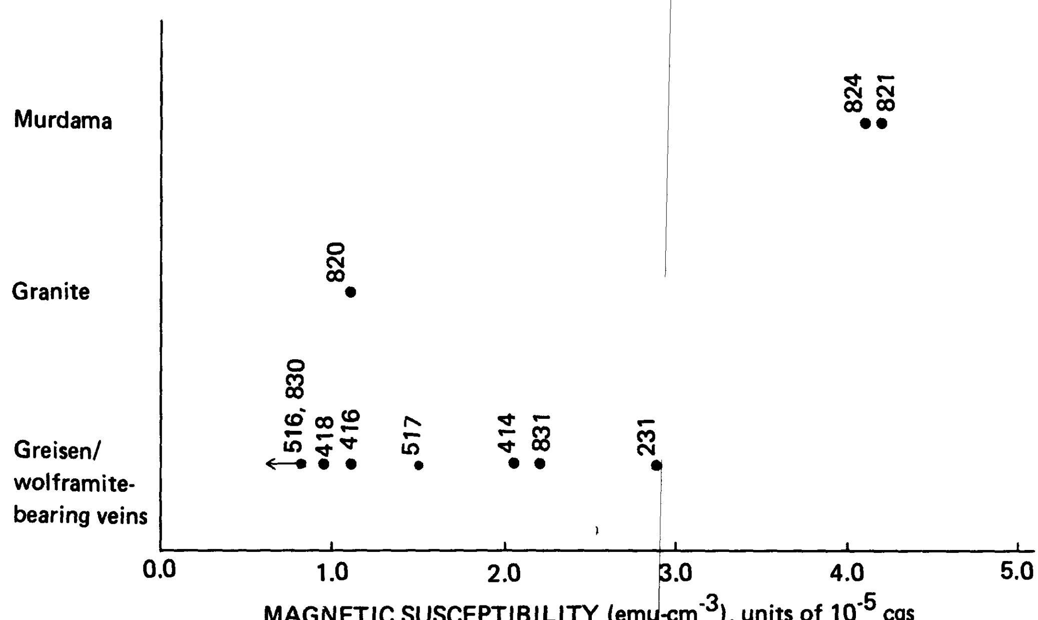


Figure 3.--Scatterplot of bulk magnetic susceptibility determinations for Baid al Jimalah West specimens. Numbers above points are the last three digits of the sample number, prefix 152-.

In order to evaluate the variation of density and magnetic susceptibility with varying degree of mineralization, the granite samples were divided into four alteration (greisenization) classes based on the petrographic descriptions in table 2: unaltered granite (one specimen); moderately greisenized granite (two specimens); strongly greisenized granite (two specimens; no visible feldspar); and strongly greisenized granite with quartz veins and wolframite present (four specimens). Plots of density versus alteration class (fig. 4) and magnetic susceptibility versus alteration class (fig. 5) show large scatter in the strongly greisenized samples having quartz veins and wolframite. This scatter is probably the result of varying degrees of weathering in these outcrop samples. Weathering produces oxidation of the sulfide minerals and leads to large variations in the measured bulk rock properties. Considering the average values for each of the classes, it is evident that there is a trend toward an increase in density and magnetic susceptibility with an increase in alteration, which is believed to correlate with an increase in volumes of wolframite and (or) sulfide minerals.

These results suggest that it may be possible to delineate the zones of most intense mineralization from detailed gravity and magnetic surveys over the vein systems. Because these are surface samples, all of which are weathered to some degree, the absolute values and the contrasts of bulk density and bulk magnetic susceptibility between mineralized and unmineralized samples should represent minimum values; therefore, the contrast and the observed geophysical effects that are predicted from these measurements should be exceeded by actual measured effects in the surveys.

The accuracy of the magnetic susceptibility measurements is 10 percent or better. The magnetic susceptibilities observed are in the expected range for granites of this composition, and the values observed for the host rocks are typical for rocks of this lithology that have greenschist facies mineral assemblages.

The electromagnetic (EM) conductivity measurements are all low and, if they are representative of the deposit, suggest that EM methods will not be successful prospecting tools for this deposit. However, because the samples are all weathered to varying degrees and those (sulfide) minerals that have high conductivities are very susceptible to weathering, the measured EM conductivities are lower bounds for the averages for the deposit. Conversely, high EM conductivities in granites and quartz vein stockworks are not common.

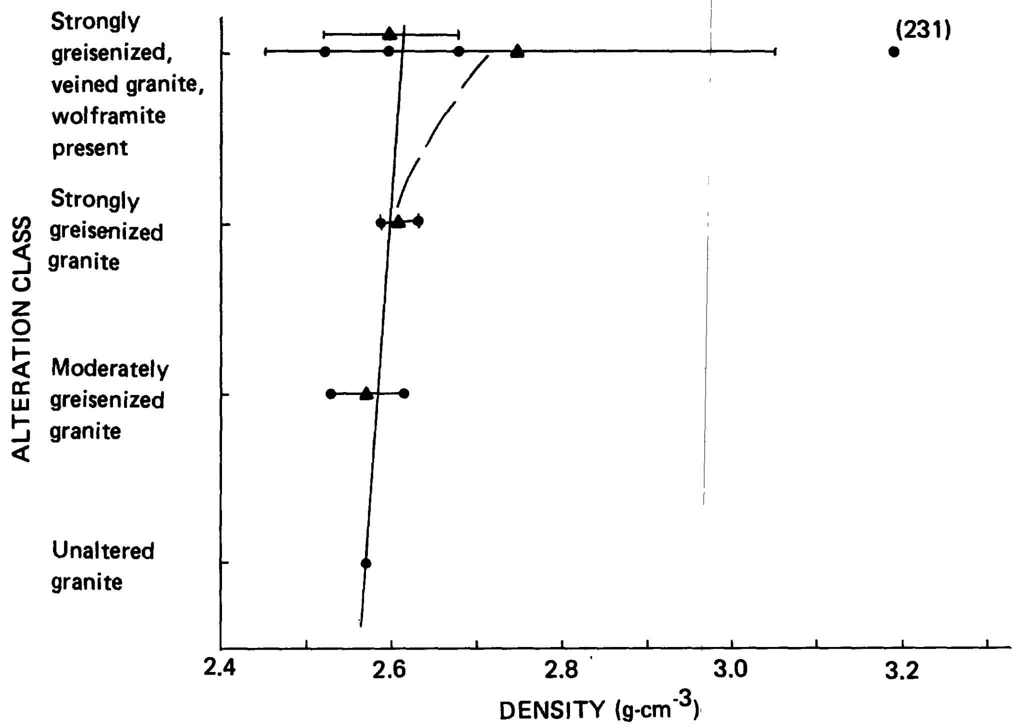


Figure 4.--Alteration class (degree of mineralization) plotted against bulk density for Baid al Jimalah West granite specimens. Point (231) represents sample 152231, which contains large amounts of coarse, bladed wolframite. Triangular symbol represents the mean, and error bars represent one standard deviation for each alteration class. For the strongly greisenized class, the mean with and without sample 152231 is shown. Solid line is an estimator illustrating the increase in density with increasing alteration class, not including sample 152231; dashed line is the estimator including sample 152231.

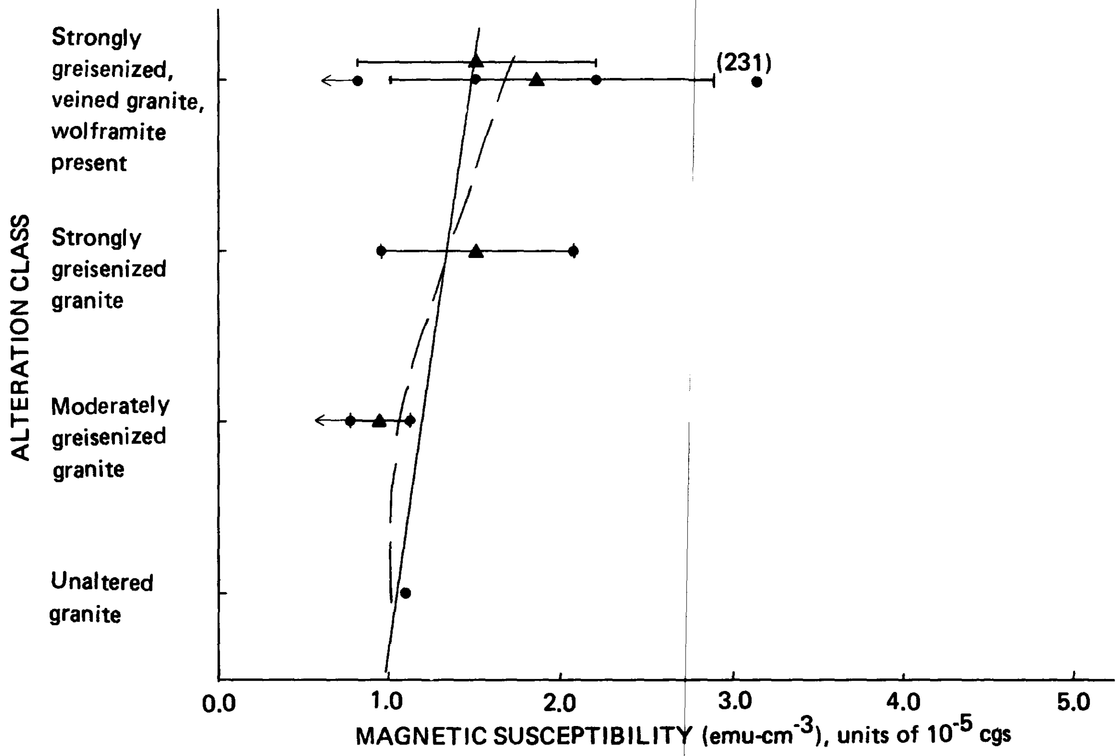


Figure 5.--Alteration class (degree of mineralization) plotted against bulk magnetic susceptibility for Baid al Jimalah West granite specimens; symbols and lines are the same as those in figure 4.

The measured induced polarization (IP) decay curves for the four specimens available are plotted in figure 6. The curve labeled "820" is the average of three nearly identical measurements for specimen 152820 (fresh granite). The induced polarization and apparent resistivities of the remaining specimens were each measured only once. Although the induced polarization response is not large, the relative variation between specimens is large, which implies that the host rock, granite, and mineralized zones should be distinguishable by their IP response. The measured IP responses are minimum values because of weathered specimens, and enhanced IP response in the field can be expected. To further compare the IP results with lithology and alteration, the curves shown in figure 6 were numerically integrated from 65 to 1690 msec to define an induced polarization chargeability (Telford and others, 1975, p. 708). Because IP response is dimensionless (mV/V), the units of chargeability are time in msec. This number is a measure of the overall induced polarization response of the specimen and is convenient for comparisons within the same suite of specimens.

The resulting induced polarization chargeability and apparent-resistivity values from the limited suite of samples available were plotted as a function of alteration class (figs. 7, 8). These results suggest that the granite and the greisenized granite could be distinguished from the host rock by both the induced polarization response and the apparent-resistivity measurements: the mineralized zones should have an induced polarization chargeability about four times that of the host rocks and an apparent resistivity of about one-fifth that of the host rocks. The data further suggest that both induced polarization and apparent resistivity will delineate zones of intense mineralization within the granite, as would be expected from the association of sulfide minerals with tungsten mineralization.

RECOMMENDED GEOPHYSICAL SURVEYS

Based on the results of the measurements of the physical properties of rocks reported above and the detailed geologic relationships outlined in Cole and others (1981), reconnaissance gravity, ground magnetic, and induced polarization (dipole-dipole method) surveys are recommended. Cole and others (1981) report that the granite is radioactive relative to other local granitic rocks and to the Murdama metasedimentary rocks; therefore, a four-channel spectrometric survey is recommended at the same ground stations as those of the magnetic survey. In order to investigate the possible relationship of the Baid al Jimalah East lead-zinc-silver deposit to the Baid al Jimalah West deposit, the proposed geophysical surveys should extend east to include both sites of mineralization.

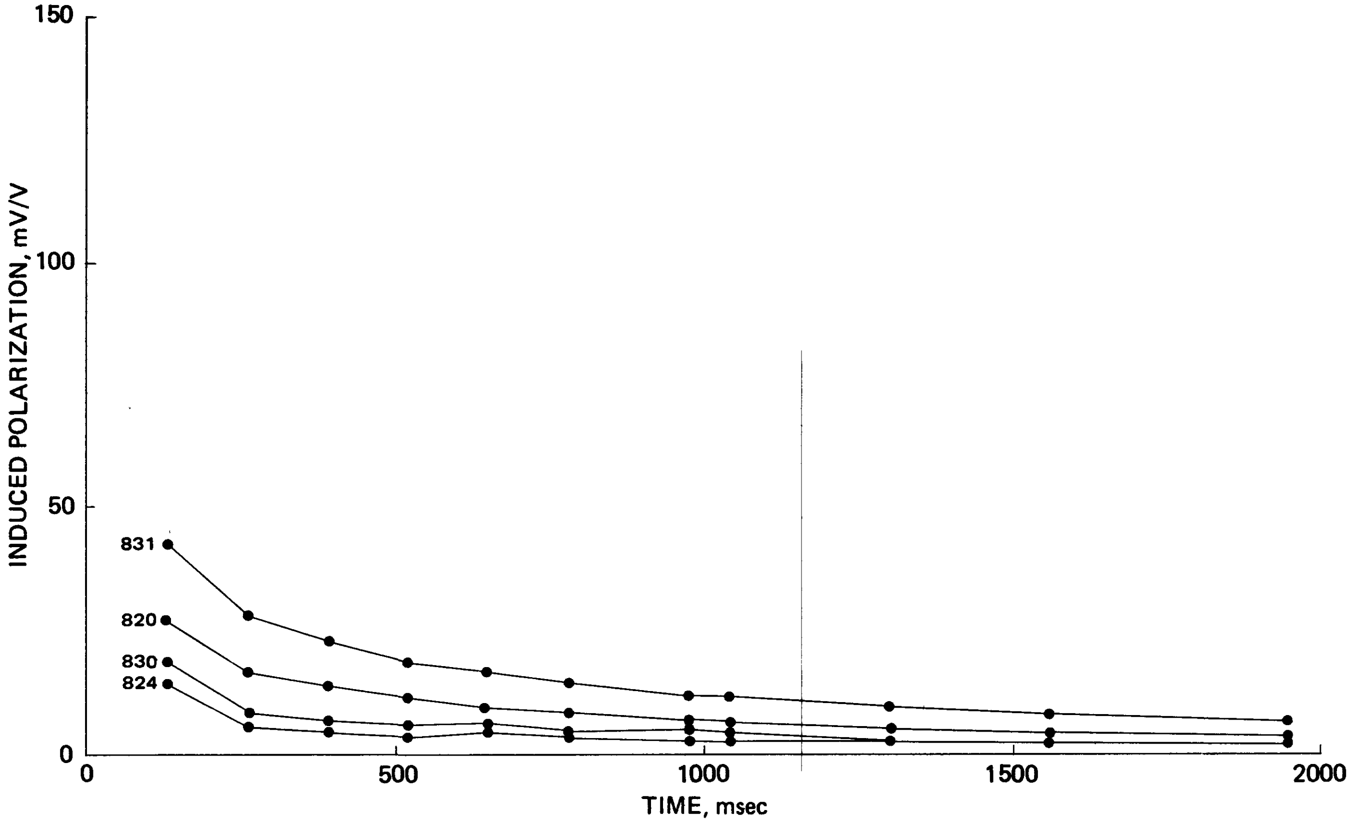


Figure 6.--Measured induced polarization decay curves for four specimens of the Baid al Jimalah sample suite. Numbers labeling the curves are the last three digits of the sample number. Curve 820 is the average of three runs of specimen 152820 (fresh granite), all of which were nearly identical.

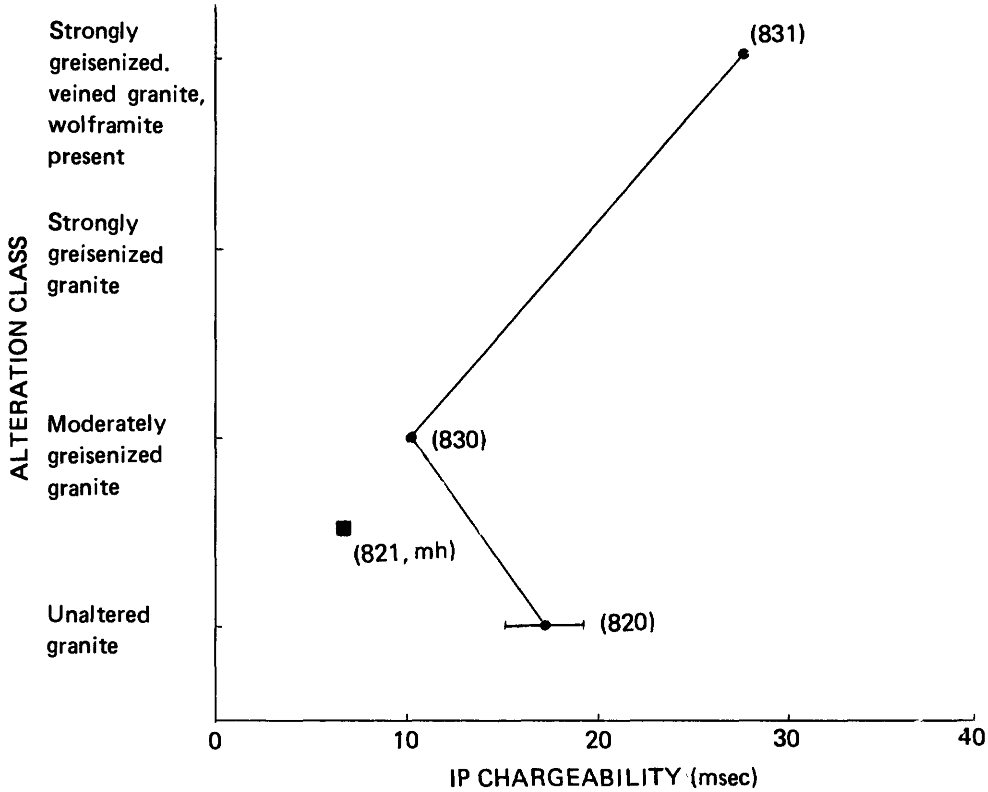


Figure 7.--Alteration class (degree of mineralization) plotted against induced polarization (IP) chargeability for Baid al Jimalah West granite specimens. Numbers in parentheses are the last three digits of the sample number. The chargeability of the sample of Murdama host rock (square symbol) is shown for comparison. Error bar for specimen 152820 represents limits of one standard deviation.

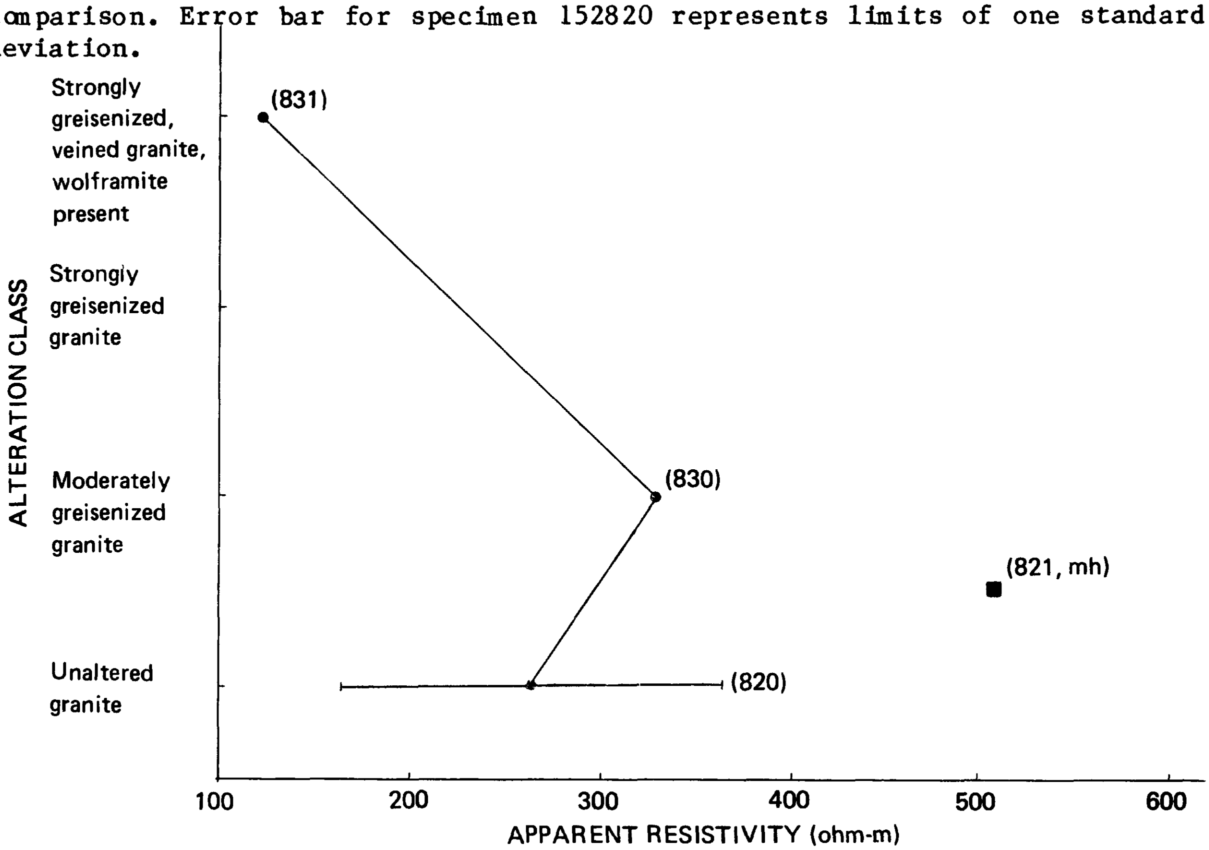


Figure 8.--Alteration class (degree of mineralization) plotted against measured apparent resistivity for Baid al Jimalah West granite specimens; symbols are the same as those in figure 7.

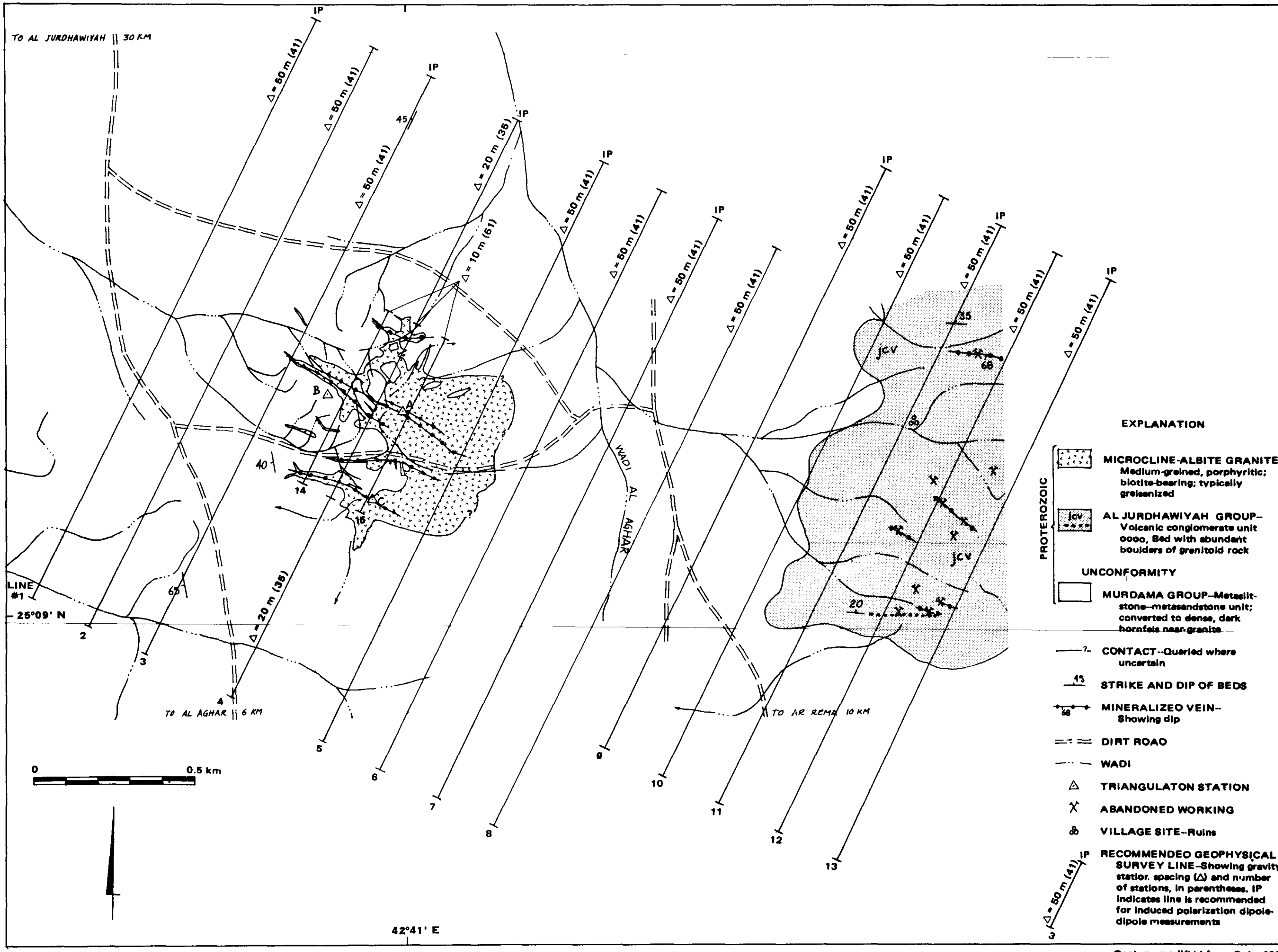


Figure 9.--Plan map of the Baid al Jimalah district showing the location of recommended gravity and induced polarization profiles. Station spacing and total number of gravity stations are shown on each profile. Profiles labeled "IP" are recommended IP dipole-dipole profiles with a dipole spacing of 25 m and an "n" up to 6. Base sketch map and geology from Cole and others (1981).

Gravity survey

The lines of the proposed gravity profiles (fig. 9) are oriented approximately normal to the strike of the vein network. Station spacing along the lines is variable from 50 m on the reconnaissance lines to 10 m across the known mineralization. Detailed data will be necessary from the mineralized area in order to evaluate the response of the mineralization, granite, and host rocks to the gravity method. Because of the small spatial extent of the mineralized zones and the small density contrast, high-precision methods will be required. An accuracy of 0.02 milligal in the observed gravity will be necessary for adequate resolution, and relative station elevations along each profile will have to be surveyed to an accuracy of ± 5 cm or better. In all, 745 stations in 15 profiles are recommended (fig. 9).

Ground magnetic and spectrometric survey

A high-precision, ground-magnetic survey is recommended. The survey should employ a recording base station magnetometer and a roving magnetometer (accuracy of one gamma or better) so that the survey results could be compiled in a map at a contour interval of two gammas. A station spacing of 25 m along profiles spaced 50 m apart, chosen to coincide with the gravity profiles, should be employed. Spectrometric measurements using a four-channel spectrometer should be recorded at the same station locations.

Induced polarization survey

Eight dipole-dipole induced polarization profiles are recommended (fig. 9, lines labeled "IP"). Electrode spacing should be 25 m and observation should be recorded out to a spacing between dipoles ("n") of 6 so that 100 to 150 m of penetration will be achieved.

REFERENCES CITED

Cole, J. C., in press, Reconnaissance geologic map of the Al Jurdhawiyah quadrangle, sheet 25/42 D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Geologic Map series

Cole, J. C., Smith, C. W. and Fenton, M. D. 1981, Preliminary investigation of the Baid al Jimalah tungsten deposit, Kingdom of Saudi Arabia: U.S. Geological Survey Saudi Arabian Mission Technical Record 20 (Interagency Report 377), 26 p.; also, U.S. Geological Survey Open-File Report 81-1223, (IR)SA-377, 26 p.

Kleinkopf, M. D., and Cole, J. C., 1982, Geologic interpretation of geophysical data for the Wadi al Jarir and Al Jurdhawiyah quadrangles, sheets 25/42 C and D, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-OF-03-01, 29 p.; also, 1983, U.S. Geological Survey Open-File Report, (IR)SA-498.

Telford, W. M., Geldart, L. P., Sheriff, R. E., and Keys, D. A., 1975, Applied geophysics: New York, London, Cambridge University Press, 877 p.